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Research Paper

Laser scanning heating method for high-temperature spectral emissivity analyses

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HIGHLIGHTS

- New method for non-contact heating of samples for emissivity analyses.
- Solution to reach high temperature in the range 300–1200 °C.
- Solution to reach homogeneous temperature field within units of °C.
- Applicability for various sample shapes and dimensions.

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ABSTRACT

A new non-contact laser heating method for the normal spectral emissivity measurements of high-temperature coatings is introduced. The method utilizes laser source in combination with scanning optics. General and specific requirements for the method development are discussed. Works on the development of the optimal heating strategy to ensure homogeneous temperature field of the area for the emissivity analyses on the sample surface are summarized. The final experimental set-up and heating procedure are described in detail. Advantages and disadvantages of the method and the method applicability are also discussed. The experimental set-up with 400 W laser is capable to heat steel substrate samples in the range of 300–1200 °C. Temperature transition of about 100 °C takes about 300 s. Temperature homogeneity in the area measured by spectrometer is within 2.5 °C in the whole temperature range.
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1. Introduction

Emissivity is a material surface property characterizing ability to emit and absorb thermal radiation. It is a relative property and is defined as a ratio of radiances of the surface and ideal black body both at the same temperature and identical spectral and geometrical conditions. In general, emissivity is dependent on material composition and surface morphology, and exhibits wavelength, temperature or angle dependences. Concerning the wavelength distribution, emissivity can have different values depending on whether one distinguishes the radiation of surfaces on a given wavelength (spectral emissivity), in a narrow wavelength band (band emissivity) or the entire spectrum (total emissivity). A detailed definition of emissivity and its relation to radiation processes is described in References 1–4.

A large number of different methods have been developed for the emissivity analyses. Direct radiometric methods come out of the physical definition of emissivity. The direct radiometric methods are the most often used to measure spectral emissivity as a basic property. These are based on the comparison of surface spectral radiance of the analyzed surface to a reference source (blackbody) at the same temperature, by the same detector, and under the same geometrical and spectral conditions. The methods differ in basic arrangement, reference sources, systems of sample clamping and heating, sample surface temperature measurement, and detection systems, as well as in the emissivity evaluation methods [5].

Temperature analyses require heating of samples. Selection of the heating method depends on the material of the sample (electrical and thermal conductivity) and on the desired range of surface temperatures. Heating up to high temperatures can be performed by halogen lamps [6], laser [4,7,8], electron beam [9] or acetylene burner [10]. Requirements of low surface temperatures can be satisfied by heating with thermostatic fluid in direct contact with the sample [2,11]. Both low and high temperature spectrometric emissivity analyses can be provided by contact [3–5,12–17] or radiative [1,6,18–21] electrical heating. In the case of electrically conductive materials, it is possible to heat the sample by passing a direct current through it [22]. Clamping of samples differs in various experimental setups and it is adapted to the heating method.

There are several general requirements to design a proper heating system. The first one is to ensure homogeneous temperature on the area of the sample surface, where the emitted radiation is measured.

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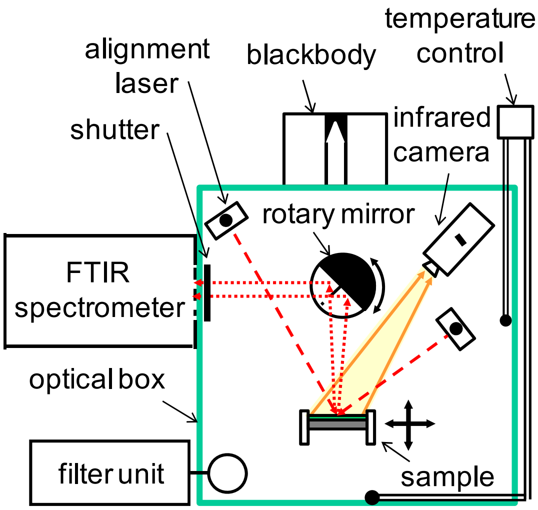

Fig. 1. Schematic view of the emissivity measuring apparatus with the optical path for the radiation coming from the sample to the detector.

Further requirement is that the radiation of the heating system should not interfere with the analyzed radiation of the sample. The heating system also has to enable the application of the sample surface temperature measurement method. Visibility of the sample for the measuring system, required temperature range and temporal changes of temperature are other obvious requirements. The mentioned processes are reflected in the evaluation of the emissivity determination uncertainty [2,23,24].

Our experimental setup of the normal spectral emissivity measurement method is described in Honnerová et al. [25]. The measuring apparatus (Fig. 1) consists of a laboratory blackbody as a reference source of radiation and FTIR spectrometer as a detection system. Infrared camera is applied to measure sample surface temperature field. The blackbody and the sample are positioned against each other outside of the spectrometer. A rotary parabolic mirror is situated halfway between them, and it switches the optical path between the blackbody and the sample. The radiation collected by the mirror enters the spectrometer through an entrance port. Optical and optomechanical components (translation stages, mirrors, aperture, shutter, alignment laser) define the analyzed area size and accomplish equal optical path from both radiation sources. The optical path is enclosed inside a box; however, no evacuating or purging is used.

Our specific requirements given to the design of the sample heating system are the following: (i) wide range of sample surface temperature from 300 up to 1200 °C, (ii) applicability both to standard samples (steel disc substrates of 25 mm in diameter and 5 mm thickness) and to samples of various shapes (circular or square profile), dimensions and materials (metals, ceramics), (iii) easy handling with samples (insertion and removal), (iv) minimum rise time to the desired temperature level (temperature increase of 100 °C in less than 5 min), and (v) limited external dimensions of the apparatus.

A laser heating method commonly used in welding of polymers [26] has been identified as a potentially proper solution of the heating task. The method applies scanning optics to ensure quasi-simultaneous heating on a defined contour by fast repositioning of the laser beam with the help of mirrors in the scanning head. Thus, the main objective of the work has been to find the optimum procedure of the laser beam spatial and temporal motion and to verify the required temperature range and homogeneity of the sample surface temperature field.

2. Experimental setup

The experimental setup is shown in Fig. 2 and consists of a laser source, scanning head, sample and infrared camera. The fiber laser (Jenoptik, maximum power 400 W, wavelength 1070 nm) with the scanning head (Scanlab HurryScan20 with f-theta objective f = 330 mm) is positioned in a certain distance to heat the back side of the sample. The front side of the sample is monitored by the calibrated infrared camera (FLIR A320, microbolometric, 320 × 240 px resolution).

The applied laser system allows working with a scanning speed of the laser beam motion up to 10,500 mm·s^{-1}. The laser beam can be positioned within the rectangle 200 × 200 mm with micrometer repeatability. Distance between the scanning head and the sample has been chosen to reach 2.5 mm laser spot diameter on the sample back surface. Power of the laser source can vary up to 400 W.

Heating tests have been conducted on refractory steel samples normally used for emissivity analyses of high-temperature coatings. The samples consist of the steel substrate of 25 mm in diameter and 5 mm thickness with a coating deposited on the front side of the sample. The reference high-temperature high-emissivity coating has been used for facilitating the noncontact analyses of temperature field by the infrared camera.

The samples are clamped to a ceramic fiber insulation case, which is attached to the optical bench by translation stages. The overall dimension of the insulation is 80 × 80 mm, and thickness is 10 mm.

Concerning the temperature requirements on the heating of the sample, it is necessary to introduce areas that are used to analyze the radiation of the sample surface. The emitted radiation from the first area (Fig. 2 – part 1) is collected by the FTIR spectrometer and it is used to determine spectral emissivity. This area has a circular shape of 7 mm diameter. The second area of the same diameter is

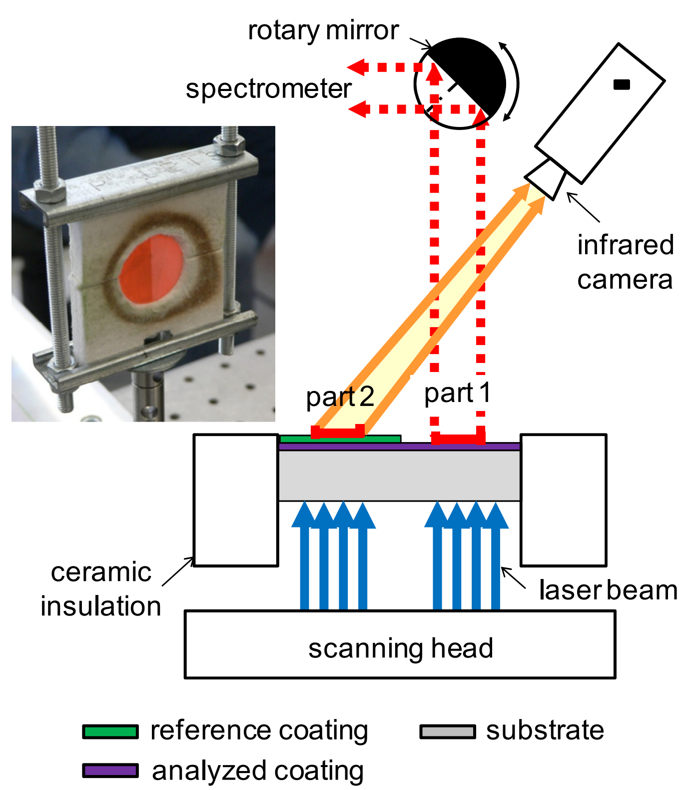

Fig. 2. Schematic view of the sample heating part of the emissivity measurement setup with photograph of the sample clamped to a ceramic fiber insulation from the infrared camera point of view.

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